



Screening Evaluations for Upland Confined Disposal Facility Effluent Quality

by Paul Schroeder, Trudy Estes, and Susan Bailey

PURPOSE: Section 404 of the Clean Water Act requires evaluation of the potential impacts of dredged material discharges from confined disposal facilities (CDFs). A joint U.S. Army Corps of Engineers (USACE) and U.S. Environmental Protection Agency (EPA) Technical Framework (USACE/EPA 2004) provides guidance for evaluation of potential contaminant pathways to determine if controls or management actions are required. Guidance for implementation of the Technical Framework is provided in the USACE Upland Testing Manual (UTM) (USACE 2003). The UTM provides a tiered approach for performing pathway evaluations. Tier II of the UTM contains a screening methodology to determine the need for pathway testing. The screens compare screening criteria, such as water quality standards, with predictions based on bulk sediment chemistry and partitioning/bioavailability relationships. One potential pathway of contaminant release from CDFs is effluent water discharged during CDF filling operations. An elutriate test procedure is available to predict chemical releases in effluent for comparison to water quality criteria, and water column bioassays are available to determine potential toxicity of effluent (Palermo and Thackston 1988a,1988b; Palermo 1985; EPA/USACE 1998; USACE 2003). This technical note provides procedures developed for Tier II of the Upland Testing Manual (USACE 2003) to conduct an initial screening evaluation of CDF effluent quality. The screening evaluation is based on equilibrium partitioning principles and conservative application of design and operating principles for CDFs. An electronic spreadsheet program to apply the screens, when finalized, may be downloaded from the ADDAMS/Dredged Material Models website <http://el.erd.c.usace.army.mil/products.cfm?Topic=model&Type=drpmat>.

BACKGROUND: One alternative for dredged material disposal is placement in diked confined disposal facilities (CDFs). CDFs are frequently used for placement of dredged material because they are often the most cost-effective and environmentally sound option. CDFs are often considered as an alternative for contaminated dredged material that is unsuitable for conventional disposal in open water. Possible contaminant migration pathways for CDFs include effluent (discharges to surface water during filling operations), surface runoff (discharges to surface water following precipitation), leachate (long-term discharges of pore water to groundwater), volatilization, and direct uptake by plants and animals. Each of these pathways may have its own standards and criteria defined by the water quality certification or other applicable laws and regulations. Federal water quality criteria constitute the baseline for surface water quality requirements. States may specify more stringent, additional, or site-specific criteria. If standards or criteria are likely to be exceeded, a variety of management options or control measures may be considered.

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Effluent is defined as a release of water and solids discharged directly to receiving waters during a CDF filling operation and would include water discharged directly over weir structures or through filter cells or retaining dikes (EPA/USACE 1998). The quality of effluent discharged from these sites is an environmental concern and is regulated as a discharge under Section 404 of the Clean Water Act. In addition, effluent standards may be set as a condition of the Section 401 State water quality certification.

Dredged material may be placed in CDFs by hydraulic or mechanical means. The rate of effluent discharge will be determined by the method of placement; the most common method is by pumping directly from a cutterhead dredge through a pipeline. Pumpout operations from hopper dredges or hydraulic offloading from barges result in intermittent hydraulic placement. Dredged material can be mechanically placed directly from barges (or possibly from trucks) with equipment located at the CDF.

Figure 1 is a schematic of an active hydraulically filled CDF. Dredged material hydraulically placed in a confined disposal area settles, resulting in a thickened deposit of material overlaid by a clarified supernatant. The supernatant waters are discharged from the site as effluent during active dredging operations. For the case of mechanical filling, the effluent discharge involves the free water, which is released during the mechanical placement operation, or the existing pond water, which is displaced by the operation. The effluent may contain both dissolved contaminants and particle-associated contaminants, adsorbed or held by ion exchange. The majority of the total contaminant concentration is typically particulate (suspended solids) associated, and the CDF should be designed to retain the suspended materials and provide adequate long-term storage capacity. Procedures for engineering CDFs for storage and solids retention are well developed (USACE 1987).

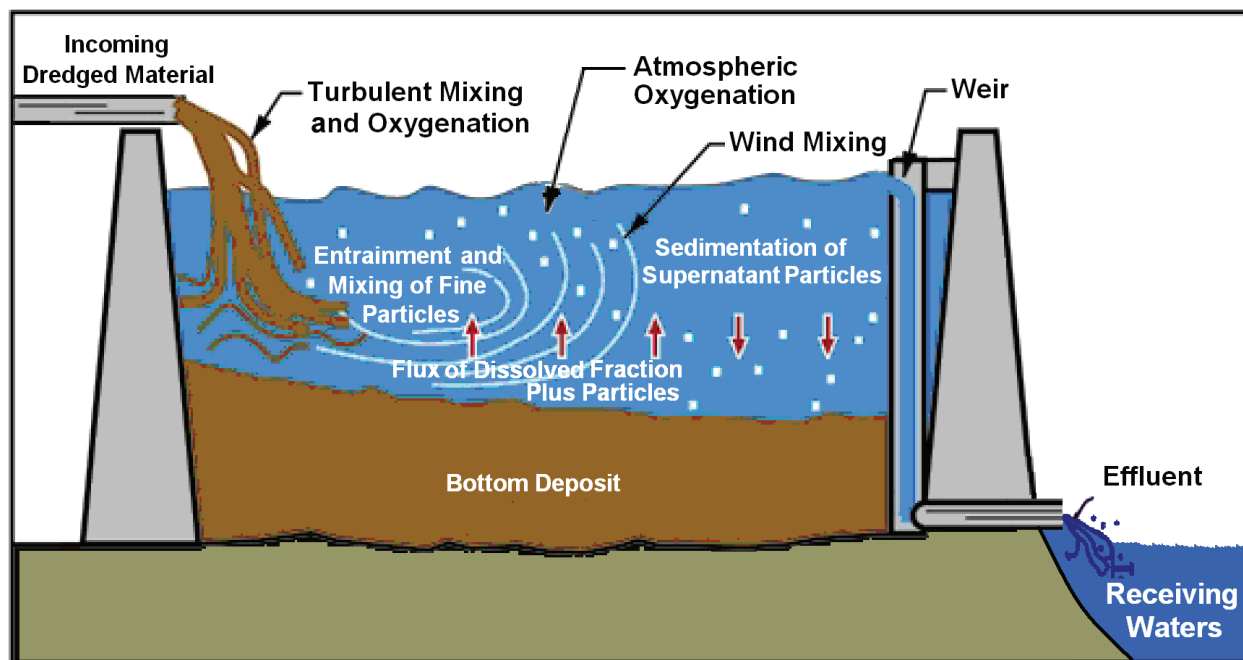


Figure 1. Schematic of factors affecting quality of effluent from confined disposal areas (USACE 2003).

Guidance for evaluating dredged material placement under Section 404 of the Clean Water Act is provided in the Inland Testing Manual (ITM), including testing procedures for effluent quality evaluation (EPA/ USACE 1998), and the Upland Testing Manual (UTM) (USACE 2003). An effluent elutriate test procedure is available to predict concentrations of contaminants in the effluent from confined disposal areas. Water column bioassays may also be conducted using the effluent elutriate test as a medium (EPA/USACE 1998).

The effects of mixing and dispersion must be considered in evaluating effluent discharges. Mixing zones (which are usually defined in terms of an allowable surface area or volume of water) are defined by the State 401 regulatory agency as a part of the Section 401 water quality certification. The point of compliance of the effluent discharge is at the limit of the mixing zone.

The effluent elutriate test and water column bioassay are Tier II and Tier III tests, respectively, in the multi-tiered approach contained in the ITM and Tier III tests in the UTM. In the remainder of this technical note, the UTM Tier structure will be used when referencing the procedures. While these tests provide a reliable means to assess effluent, they are expensive and time-consuming. Many projects involve sediments that have minimal potential for impact; therefore, screening procedures are needed to determine when the tests should be conducted.

BASIS OF EFFLUENT SCREENING EVALUATION: The effluent screening procedures presented here are based on equilibrium partitioning principles and conservative application of design and operating principles for CDFs. Procedures are given for evaluating effluent releases from hydraulically dredged or offloaded sediments. The evaluation utilizes site-specific data input by the user and default values for pertinent parameters to calculate predicted effluent quality at the weir or at the edge of the mixing zone for a given sediment contaminant concentration. If the predicted effluent quality exceeds the standards at the point of compliance, additional testing and evaluations are necessary.

The same principles can be used to calculate a maximum allowable bulk sediment concentration that will result in the effluent meeting water quality standards at the point of compliance. Actual bulk sediment concentrations above the maximum allowable bulk sediment values would result in additional testing and evaluations.

Where sediments are hydraulically dredged, the effluent produced is a result of mixing material from two systems initially at equilibrium (sediment/pore water and water column/suspended solids) in which the contaminants present are partitioned between the solids and the surrounding fluid. When these systems are mixed, a new state is created that is bounded by theoretical conditions: 1) the contaminants in the mixture will establish a new equilibrium between the solids and the water, or 2) dissolved concentrations in the effluent will be a simple function of mixing the pore water and the carrier water.

The retention time in most CDFs is on the order of one day to a few days. Contaminant partitioning between the solid and aqueous phases in the influent slurry is not likely to reach equilibrium due to the short contact time after mixing of in situ sediments with carrier water and the limited oxidation occurring in the influent slurry. Equilibrium partitioning is therefore considered to be a boundary condition for effluent quality, and a screen based on equilibrium

partitioning would therefore be conservative. Effluent quality predicted by simple mixing provides the second boundary condition.

Predicted effluent quality. The effluent quality screening protocol for hydraulic disposal of dredged material in a confined disposal facility was developed based on the equilibrium and mixing boundary conditions, using observations from five field sites for validation. The protocol produces two estimates of the effluent concentration at the weir based on these boundary conditions. The larger of the two estimates is used for comparison to the screening criteria. The equilibrium partitioning calculations assume that only a fraction of the metals in the sediment is leachable. The fraction varies from metal to metal. It further assumes that contaminant concentration in the background water is completely leachable (dissolved only). In both cases, dilution occurring within the mixing zone at the point of discharge is taken into consideration in calculating the predicted concentration that is compared to water quality criteria.

For mechanically dredged sediments, there is typically little or no effluent production. Site water entrained with the dredged sediments may mix partially with pore water during barge placement and offloading, but the relative quantity of pore water to site water would be expected to be small, as extensive mixing does not occur. An initial release of entrained water may occur during placement in the CDF, but when materials are being placed over permeable foundation materials or partially desiccated dredged material, seepage into the underlayers is likely to eliminate effluent flows. Some effluent production might occur if there is a precipitation event during placement of the material into the CDF. In this case, the effluent would be expected to be very similar in character to runoff from unoxidized materials. Procedures for estimating the quality of unoxidized surface runoff should therefore be used to estimate effluent quality for mechanically placed materials (Schroeder et al., in preparation). As for hydraulic dredging, dilution occurring within the mixing zone at the point of discharge is taken into consideration.

Maximum allowable sediment concentration. The above principles can be applied to a similar protocol used to predict the maximum allowable bulk sediment concentration for which the resulting effluent would meet water quality standards for hydraulically placed material. In this screening approach, two values of allowable bulk sediment concentration are calculated based on the two boundary conditions. The smaller of the two estimates (smaller calculated sediment contaminant concentration resulting in effluent meeting water quality standards) is then used as the screening criteria. As stated in the previous paragraph, effluent from mechanically placed material is very limited in quantity, and would be similar to unoxidized surface runoff. Allowable sediment concentrations for mechanical dredging should therefore be equivalent to those for unoxidized surface runoff (Schroeder et al., in preparation). The procedure for estimating maximum allowable sediment concentration is the reverse of the procedure for predicting effluent concentration, and is not explicitly presented here. The maximum allowable bulk sediment concentration for each contaminant can be found by varying the bulk sediment concentration so that the predicted effluent concentration is equal to the water quality standard.

INPUT PARAMETERS: An electronic spreadsheet program is available to apply the screens to include all necessary calculations. Site-specific parameters input by the user include the following:

- Bulk sediment concentration (q) in mg/kg - the concentration of contaminants of concern in the in situ sediments.
- Carrier water concentration (C_c) in $\mu\text{g/L}$ - the dissolved concentrations of the contaminants of concern at the dredging site.
- Background water concentration (C_B) in $\mu\text{g/L}$ - the dissolved concentrations of the contaminants of concern at the point of discharge from the CDF, within the mixing zone. (Note that the background or receiving water and dredging site water are often the same water body).

Several default parameters are also utilized in the spreadsheet calculations. Default parameters are derived from the literature, previous or current testing, or site information and are specific to hydraulic or mechanical disposal. Default parameters can be altered for site-specific conditions where indicated; for the effluent screen, they include the following:

- Specific gravity of sediment (SG) – measured or default value.
- Water density (ρ_w) – 1 g/cm^3 .
- Dilution within mixing zone for effluent (D) – In the present version, this pertains only to upland CDFs (assumes no dilution occurs within the CDF from ponded conditions existing prior to material placement). The dilution occurring within the mixing zone is calculated using a dilution factor, a user input value calculated using estimates of effluent and receiving water flow rates and mixing zone volume.
- Allowable background exceedance (x), % – This parameter applies when contaminant concentrations in the background or carrier water exceed water quality criteria. An acceptable, short-term exceedance of water quality criteria is defined under a regional area decision (RAD) or local area decision (LAD).
- Influent slurry solids concentration (TSS_{slurry}) in g/L – This parameter is a function of the grain-size distribution of the sediment, and a value can be calculated using the following relationship, if the grain-size distribution is known. Default values are also provided.

$$TSS_{\text{slurry}} = \% \text{ fines} + 3 * \% \text{ coarse} \quad (1)$$

- Influent porosity (n) – Influent porosity is calculated from input parameters using the influent slurry solids concentration, the specific gravity of the sediment (SG), and the density of water (ρ_w , 1 gm/cm^3).
- Total organic carbon content (TOC), % – measured value.
- Silt & clay fraction (SCF), % – measured value.
- Dissolved organic carbon content in pore water (DOC), mg/L – measured value.
- In situ sediment water content (w), % – measured value.

- In situ void ratio (e) – calculated using the specific gravity of the sediment (SG) and the in situ sediment water content.
- Porosity of sediment (n) – calculated from the in situ void ratio.
- In situ solids concentration (TSS_{sed}) in g/L – calculated using the porosity of the sediment (n) and the specific gravity (SG) of the sediment.

Chemical specific parameters utilized in the effluent computations include octanol/water coefficient (K_{ow}), distribution coefficient (K_d), normalized unoxidized leachable fraction (LF), and marine or freshwater chronic water quality criteria. There is also provision for user input criteria. Values for these parameters were taken from various sources, including Warren and Streng (1994), Ruiz et al. (2000), and EPA (1998 and 1999).

PREDICTED EFFLUENT QUALITY CALCULATIONS: The equations used in the calculations for hydraulic filling operations are presented below. The procedure can be applied to determine highest dissolved contaminant concentrations exiting the weir or at the mixing zone boundary. For both boundary conditions, the leachable sediment contaminant concentration is calculated from measured bulk sediment concentration and the leachable fraction. Additional testing and evaluation are required if predicted effluent concentrations exceed the water quality standards.

Leachable Contaminant Concentration – Mixing and Equilibrium Boundary Conditions. The following steps are performed in calculating the predicted effluent concentrations.

1. Calculate the leachable contaminant concentration from the solids in the sediment, based on measured bulk sediment concentration and the leachable fraction. For metals, the leachable contaminant concentration ($q_{sediment}^*$) is normalized using the silt and clay fraction and adjusted for leachable fraction. For organic contaminants, the leachable contaminant concentration ($q_{sediment}^*$) is equal to the allowable bulk sediment concentration (LF = 1). The following equations are used:

Metals/Inorganics:

$$q_{sediment}^* = LF * \frac{q}{SCF/100} \quad (2)$$

Organics:

$$q_{sediment}^* = LF * q \quad (3)$$

where

$q_{sediment}^*$ = leachable contaminant concentration in SCF at equilibrium in the sediment, mg/kg

q = measured contaminant concentration in bulk sediment, mg/kg

SCF = silt/clay fraction (%)

LF = leachable/soluble fraction of contaminants in the SCF, ($LF_{\text{organics}} = 1$)

LF is the leachable fraction of the bulk concentration in the fine-grained materials. In the program, LF is a default parameter, and values were selected from elutriate testing, field observations, and other empirical evidence. When the screen is used for a UTM Tier II evaluation to determine the need for Tier III testing, site-specific data such as is derived from the elutriate test is often unavailable and default values must be utilized. Improvements to the default values can be made, however, if elutriate testing results from prior evaluations are available.

Predicted Effluent Concentrations - Equilibrium Boundary Condition

2. Calculate the leachable contaminant concentration per mass solids in the influent slurry using the leachable contaminant concentration of the bulk sediment, including the mass of contaminants in the carrier water. The following equation is used:

$$q_{\text{slurry}}^* = q_{\text{sediment}}^* + \frac{(TSS_{\text{sed}} - TSS_{\text{slurry}})C_C}{TSS_{\text{sed}} * TSS_{\text{slurry}}} \quad (4)$$

where

q_{slurry}^* = leachable contaminant concentration at equilibrium in the influent slurry (mass of contaminant associated with sediment solids, pore water and carrier water per mass solids), mg/kg

TSS_{sed} = total suspended solids concentration in the in situ sediment, g/L

TSS_{slurry} = total suspended solids concentration in influent slurry, g/L

C_C = dissolved carrier water contaminant concentration, $\mu\text{g/L}$

3. Calculate the dissolved contaminant concentration at the weir. The following equation is used:

$$C_{\text{effl}} = \frac{q_{\text{slurry}}^* (1000 \mu\text{g}/\text{mg})(1 - n_{\text{slurry}}) \rho_s}{n_{\text{slurry}} + K_d (1 - n_{\text{slurry}}) \rho_s} \quad (5)$$

where

C_{effl} = dissolved contaminant concentration at weir based on equilibrium, $\mu\text{g/L}$

n_{slurry} = porosity of slurry

K_d = unoxidized equilibrium distribution coefficient, L/kg

ρ_s = density of solid particles, kg/L

For inorganic contaminants and organic tins, the K_d values were selected from literature sources, past elutriate testing, field observations and other empirical evidence. For organic contaminants (PAHs, organophosphorus pesticides, chlorinated pesticides, semivolatile organic compounds, PCBs and dioxins), K_d is calculated as follows:

$$K_d = \frac{0.617 * FOC * K_{OW}}{1 + (0.617 \times 10^{-6} DOC * K_{OW})} \quad (6)$$

where

FOC = fraction organic carbon in the solids (TOC (%) /100)

K_{OW} = octanol-water equilibrium partitioning coefficient

DOC = dissolved organic carbon concentration in pore water, mg/L

Predicted Effluent Concentration – Mixing Boundary Condition

4. Calculate the dissolved contaminant concentration in sediment pore water from the leachable concentration based on equilibrium partitioning of the contaminant between the sediment solids and the pore water. The following equation is used:

$$C_{se\ dim\ ent} = \frac{q_{se\ dim\ ent}^* (1000 \mu g / mg) (1 - n_{se\ dim\ ent}) \rho_s}{n_{se\ dim\ ent} + K_d (1 - n_{se\ dim\ ent}) \rho_s} \quad (7)$$

where

$C_{sediment}$ = dissolved contaminant concentration in sediment pore water, $\mu g/L$

$n_{sediment}$ = porosity of sediment

5. Calculate the effluent concentration based on pore water dilution with carrier water. The following equation is used:

$$C_{eff2} = \frac{TSS_{sed} C_C + TSS_{slurry} (C_{se\ dim\ ent} n_{se\ dim\ ent} - C_C)}{TSS_{sed} + TSS_{slurry} (n_{se\ dim\ ent} - 1)} \quad (8)$$

where

C_{eff2} = dissolved contaminant concentration at weir based on mixing, $\mu g/L$

C_c = carrier water concentration, $\mu g/L$

Determination of Requirement for Effluent Testing Based on Maximum Predicted Effluent Concentration. Compare the largest of the predicted effluent concentrations for both boundary conditions to constituent solubility. If the maximum predicted value is greater than solubility, the default maximum effluent concentration is taken to be the constituent solubility. Calculate the predicted dissolved contaminant concentration at the mixing zone boundary considering the allowable mixing zone, background concentration, and dissolved contaminant concentration at the weir, using the maximum predicted effluent concentration. The following equation is used:

$$C_P = \frac{C_{eff} + D C_B}{D + 1} \quad (9)$$

where

- C_P = predicted dissolved contaminant concentration at mixing zone boundary, $\mu\text{g/L}$
- C_{eff} = maximum predicted dissolved contaminant concentration at weir, $\mu\text{g/L}$
- D = dilution ratio available in mixing zone (background water volume to effluent volume)
- C_B = dissolved background contaminant concentration of receiving water, $\mu\text{g/L}$

The predicted contaminant concentration C_P is compared to the target concentration C_T and a ratio of $C_P:C_T$ is computed, where:

- C_T = target dissolved contaminant concentration at mixing zone boundary, $\mu\text{g/L}$
- = selected water quality criteria, $\mu\text{g/L}$, when greater than dissolved background concentration plus allowable exceedance, $(1 + x/100)*C_B$
- = dissolved background concentration and allowable exceedance, $(1 + x/100)*C_B$, $\mu\text{g/L}$, when water quality criteria is less than or equal to the background concentration plus allowable exceedance $(1 + x/100)*C_B$
- x = background exceedance allowance, percent

If C_P exceeds applicable target criteria, C_T ($C_P/C_T > 1$), UTM Tier III testing is needed.

MAXIMUM ALLOWABLE SEDIMENT CONCENTRATION CALCULATIONS: The protocol can be applied with some modification to determine the maximum allowable bulk sediment concentrations resulting in effluent meeting water quality standards. Although the detailed procedure is not presented here, a separate electronic spreadsheet program is available upon request to apply the screens in reverse order to estimate a maximum allowable sediment concentration resulting in effluent meeting water quality standards. As with the above procedure, two values of the maximum allowable bulk sediment concentration are calculated based on the two boundary conditions (mixing and equilibrium). The smaller of the allowable bulk sediment concentrations is then selected as the screening criteria for allowable sediment

concentration. This is then compared to the actual bulk sediment concentration. Ratios of actual to allowable greater than 1 indicate water quality criteria may be exceeded, and UTM Tier III testing is needed.

Alternatively, the maximum allowable bulk sediment concentration for each contaminant can be found by varying the bulk sediment concentration so that the predicted effluent concentration is equal to the water quality standard. Additional testing and evaluation are required if actual sediment concentrations exceed the maximum allowable sediment concentration.

VERIFICATION: The screening protocol was evaluated using data from five dredged material disposal projects: Craney Island, Black Rock, Mobile, Savannah, and Hart Miller Island. The predicted effluent concentrations of various metals and PCBs were compared with field measurements. The results of the comparisons for metals are shown in the following graph (Figure 2) along with comparisons of the modified elutriate predictions to the field results. Ratios less than one indicate effluent concentrations were underpredicted, on average, while ratios greater than one indicate overprediction of effluent concentrations. Predicted to measured PCB concentrations at Black Rock Harbor are illustrated in Figure 3. On average, both the screening protocol and the elutriate test produced concentration estimates approximately twice the field value for metals. For both metals and PCBs, only the screen was equal to or greater than the field values in all cases. The elutriate test underpredicted concentrations in some cases and overpredicted others. Based on these results, the screening protocol appears to be the more conservative estimating method.

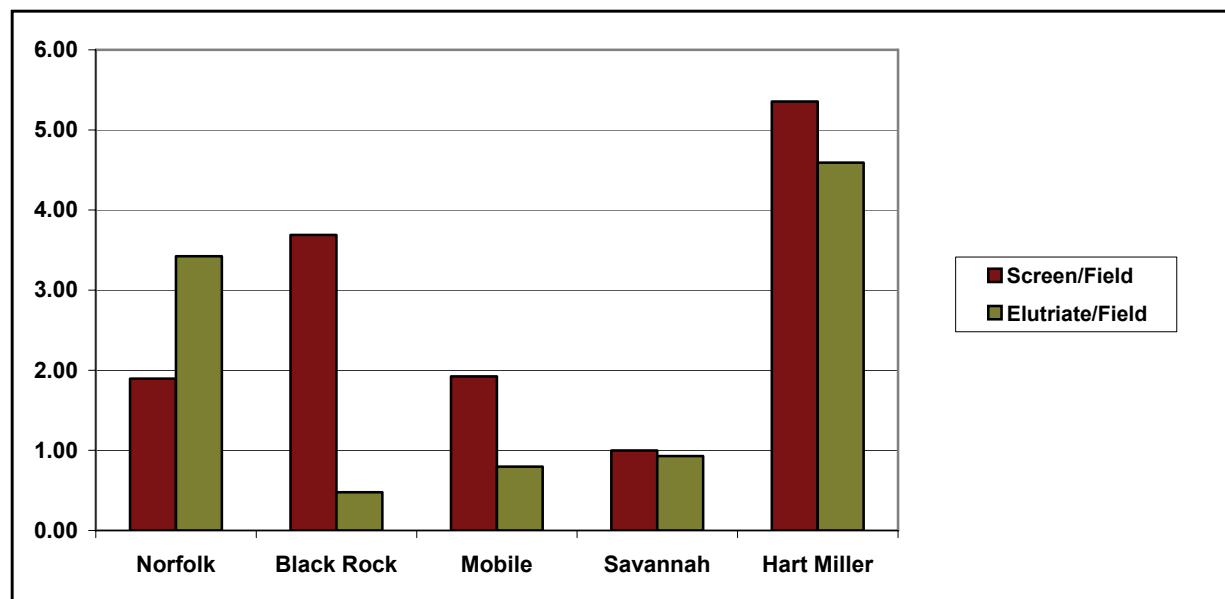


Figure 2. Ratio of screen and elutriate metals concentrations to field concentrations.

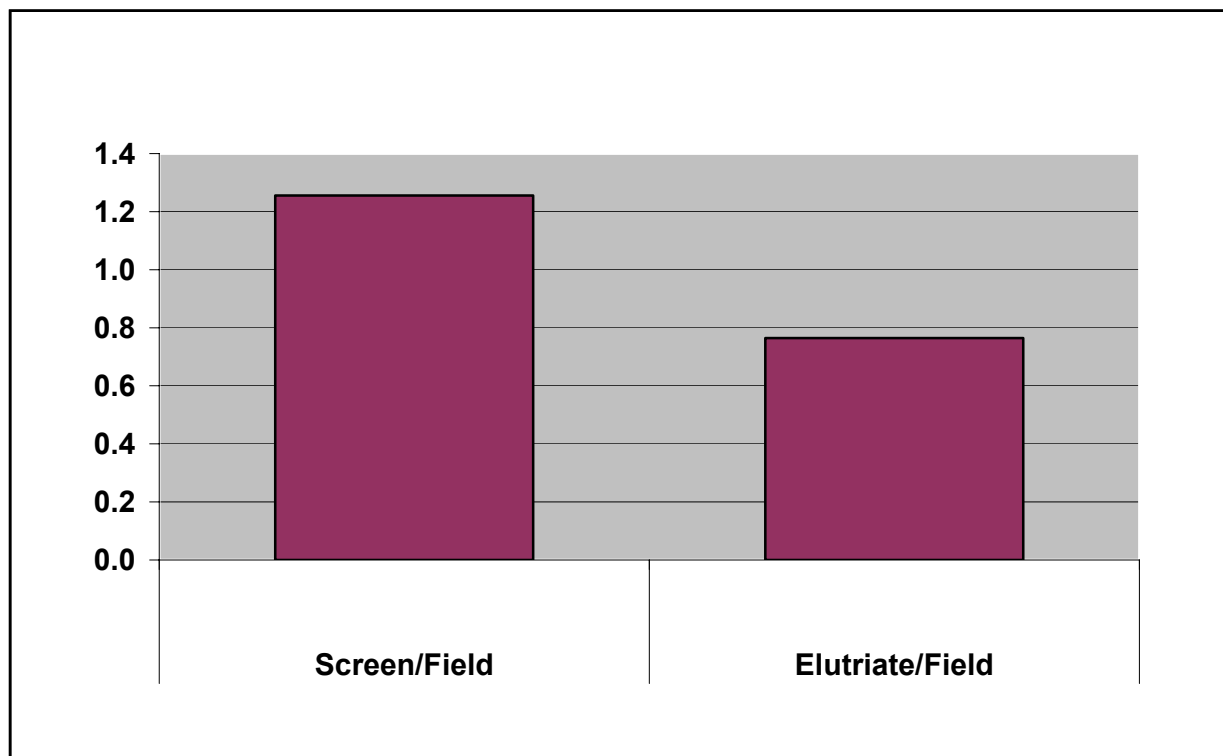


Figure 3. Ratio of predicted to field PCB concentrations at Black Rock Harbor.

SUMMARY: This technical note provides procedures for evaluating CDF effluent quality at the initial screening tier of a multi-tiered approach. The screening evaluation is based on equilibrium partitioning principles and conservative application of design and operating principles for CDFs. An electronic spreadsheet program is available to apply the screens, and the screening procedures will be included in future testing manuals for evaluation of proposed placements of dredged material in CDFs.

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